STEVENS INSTITUTE OF TECHNOLOGY 1870

## Ph.D. DISSERTATION DEFENSE

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| **Candidate:** | Erik Pearson |
| **Degree:** | Doctor of Philosophy |
| **School/Department:** | Charles V. Schaefer, Jr. School of Engineering & Science/ Mechanical Engineering |
| **Date:** | Wednesday, August 16th, 2023 |
| **Time/Location:** | 11:00 AM / ABS 301 |
| **Title:** | Mapping, Localization, and Navigation for Robust Autonomous Inspection of Indoor Environments with Unmanned Ground Vehicles |
| **Chairperson:** | Dr. Brendan Englot, Department of Mechanical Engineering. |
| **Committee Members:** | Dr. Enrique Dunn, Department of Computer Science<br>Dr. Hamid Jafarnejad Sani, Department of Mechanical Engineering<br>Dr. Long Wang, Department of Mechanical Engineering |

## ABSTRACT


The need for autonomous infrastructure inspections performed by mobile robots is becoming increasingly prevalent, to mitigate human error and inspect critical infrastructure with increased frequency, while reducing costs. Accurate mapping, localization and navigation are required to perform autonomous inspection tasks in indoor environments with unmanned ground vehicles (UGVs). Computer vision and precise manipulator control are necessary for successful handheld sensor interactions. This dissertation will discuss completed work towards these capabilities.

Occupancy grid maps are used to condense large volumes of sensor data into manageable and useful data structures for planning and decision-making. Most such maps only consider three possible states for each grid cell: free, occupied and unknown. However, occupancy grid maps' fixed spatial resolution limits their ability to identify sharp changes in occupancy. We propose a novel multi-resolution occupancy mapping algorithm that uses Bayesian generalized kernel inference to distinguish uncertain regions from unknown regions within an occupancy grid, permitting autonomous inspections to address each category separately.

Reliance on electrical power has become a necessity in many parts of the world. Maintaining the equipment used for power distribution is critical. Handheld partial discharge (PD) sensors offer a method for routine inspections to identify degrading hardware before failure. Multiple steps are required to practically enable a mobile manipulation robot platform to perform these inspections.

While simultaneous localization and mapping (SLAM) is effective for navigating an unknown environment, repetitive inspection tasks are often better-served by relying on localization relative to a prior, existing map. By registering current LiDAR data to a global reference map, waypoints assigned to the global frame can be sent to the robot. A framework for localization using prior LiDAR-derived maps will be presented, and leveraged within a novel system architecture supporting multi-session autonomous navigation of a UGV to designated waypoints throughout an indoor environment of interest.

A unique UGV platform has been developed that incorporates a six degree-of-freedom manipulator arm with a custom end-effector to interact with a handheld PD sensor. This integration will be discussed, along with the development and testing of algorithms needed to support its autonomous operations within a substation. Coordination between the UGV and manipulator arm using their respective sensing modalities and computing capabilities is required for successful autonomous inspections. Real-time image processing enables precise localization for robot interactions with points of interest within the environment. Automated manipulator control and PD sensor button-pressing interactions are also discussed. With each of these features implemented, a complete autonomous inspection routine was successfully operated within an electric substation.